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TAC-TR-62-24

OPERATIONAL TEST AND EVALUATION

DOPPLER NAVIGATION SYSTEM FOR F-100 AIRCRAFT

(RYANAV IV DOPPLER)

MAY 1963

HEADQUARTERS
TACTICAL AIR COMMAND
United States Air Force
Langley Air Force Base, Virginia

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Doppler Navigation System for F-100
(RYANAV IV Doppler)

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Publication Review

This report has been reviewed and is approved

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HEADQUARTERS
TACTICAL AIR COMMAND
United States Air Force
Langley Air Force Base, Virginia

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FOREWORD

The authority for the conduct of this test, RYANAV IV Doppler Navigation System for F-100 Aircraft, TAC Test 62-24, is contained in AFR 80-14 and was directed by TAC test order, number as above, dated 17 May 1962. The test was conducted by the Training Research and Development Division of the USAF Fighter Weapons School, Nellis Air Force Base, Nevada.

The following persons were responsible for the actual conduct of the test and for preparation of the final report:

TAC Test Supervisor	Lt Colonel R. C. Allen
Project Officer	Captain F. E. Liethen
TAC Test Monitor	Major R. T. Starke

ABSTRACT

The capability of a prototype RYANAV IV Doppler Radar to provide accurate inputs to the AN/ASN-25 Computer and the BANDS Pictorial Display was evaluated at Nellis Air Force Base, Nevada, during the period 1 August 1962 to 1 February 1963. The system was installed in an F-100F aircraft with the doppler radar mounted in an external fuel tank. The RYANAV IV Doppler Radar was very accurate but the full potential of the system is limited by the inaccurate heading reference system presently installed in the F-100 aircraft. The altitude and attitude capability of the system is more than adequate for normal tactical fighter navigational maneuvering. A navigation system having performance characteristics of the type tested would greatly improve the operational capability of tactical strike aircraft, particularly in marginal weather or at night.

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1. INTRODUCTION:

a. It has been recognized that a significant increase in the operational capability of the F-100, in particular on long-range, low level missions, can be obtained by the addition of an accurate self contained navigation system. PACAF is presently operating F-100 aircraft with a navigation system consisting of the AN/APN-102 Doppler Radar and AN/ASN-25 Computer with some success. However, when considering the modification of the TAC and USAFE F-100 aircraft, cognizance must be taken of the fact that the status of technology has advanced to permit replacement of the AN/APN-102 with a less expensive, lighter, more accurate and more operationally capable doppler.

b. This test is an evaluation of a currently available system. Ryan Electronics agreed to provide, install, and maintain the RYANAV IV Doppler at no cost to the government. They also agreed to support the doppler, AN/ASN-25 Computer, and BANDS display combination in an F-100 aircraft for operational evaluation by TAC. Only the doppler system will be discussed in detail in this report since the other systems were thoroughly discussed in the following TAC test reports.

(1) TAC-TR-60-51, November 1961. Operational Test and Evaluation - Doppler Navigation System for F-100 Aircraft, unclassified.

(2) TAC-TR-61-36, January 1962. Bendix Doppler Pictorial Display, unclassified.

2. DESCRIPTION OF TEST ITEMS: The navigation system tested consists of three major components and uses information from the J-4 Compass System.

a. RYANAV IV Doppler Radar: The RYANAV IV Doppler Radar is a CW, K-band system using three beams which are fixed with respect to the aircraft. The following are the contractor stated characteristics of the RYANAV IV:

Ground Speed	100 to 1600 knots
Drift Angle	30 degrees
Vertical Velocity	0 to $\pm$ 60,000 FPM
Altitude:	
Over land and sea (Beaufort #1)	0 to 70,000 feet

Accuracy (Standard Deviation)

Ground Speed - Land	0.5% $\pm$ 0.6 knot
- Sea	0.6% $\pm$ 0.6 knot
Drift Angle	$\pm$ 0.4 $\pm$ $(30/Vg)^{o}$
Ground Track Angle	$\pm$ 0.4 $\pm$ $(30/Vg)^{o}$
Weight	45 pounds
Volume	1.7 Cubic Feet
Power Consumption	330 Watts
Frequency	13,300 Megacycles
Transmitter Power	1.5 Watts

The system provides outputs of ground speed, drift angle, and ground track.

b. AN/ASN-25 Navigation Computer: The AN/ASN-25 Navigation Computer is a rhumb line (line of constant bearing) navigation system. The control indicator has two vertical rows of counters, each row displaying Desired Track, Nautical Miles To-Go, and Nautical Miles Off-Track. The system switches automatically from one leg to the other when the Nautical Miles To-Go dial reaches zero. The AN/ASN-25 requires heading information from the aircraft heading reference and ground speed and track from a doppler radar. The following is a technical description of the ASN-25:

Ground Speed	70 to 2000 knots
Distance Per Leg	0 to 999 NM
Track Angle	0^{o} to 360^{o}
Distance Off-Track	0 to 99 NM
Accuracy	0.2%
Temperature	$-55^{o}C$ to $+71^{o}C$

Pressurization	None
Powered Required	150 VA, 400 cps, 115 v
Electrical Inputs	Ground Speed and Track
Manual Inputs	Distance and Desired Track
Weight	23 Pounds
Volume	0.4 Cubic Feet

The navigation computer provides steering information to the ID-351 Course Indicator, Nautical Miles To-Go to the Short Range Indicator, and a signal proportional to along-track and cross-track velocity to the BANDS Pictorial Display.

c. Bendix Air Navigation Display System: The Bendix Air Navigation Display (BANDS) is designed to automatically provide a continuous pictorial display consisting of past and present position on a standard navigation chart. Electrical inputs to the BANDS computer are signals proportional to along-track and cross-track velocity with respect to desired track. The system consists of a control panel, computer, and flight plotter which holds a map strip 10 inches wide and 12 feet long. The system has the capability of dead reckoning (DR) operation in case of input failure and can be manually updated whenever the map position and aircraft position are known not to coincide.

d. J-4 Compass: The J-4 Compass is the standard F-100 heading reference that has been modified with an 8260 Synchro Compensator. The 8260 Synchro Compensator is designed to provide compass heading information to various external equipments without affecting the accuracy of the magnetic compass indication. It also affords precise vernier measurements to one-tenth degree for compass calibration purposes.

e. Test Installation: The F-100F aircraft used in this test is the prototype of the F-100F-20 series and was previously modified with an AN/APN-102, an AN/ASN-25 and a BANDS roller map. The Ryan doppler radar, along with some associated telemetry transmitting equipment, was installed in a 200-gallon external fuel tank mounted on the right hand, inboard station. The doppler antenna was mounted forward on the underside of the drop tank. The doppler control panel was installed on the right-hand console in the front cockpit and an adapter box was installed on the rear cockpit right-hand console.

The AN/ASN-25 Computer System was installed in its normal location. The BANDS Pictorial Display was mounted on a bracket above the instrument panel. Its control panel was installed on the front right-hand console. Detailed installation information for these two systems is contained in their respective TAC Test Reports 60-51 and 61-36.

3. PURPOSE OF THE TEST: The purpose of the test was to determine the suitability and accuracy of the RYANAV IV Doppler Radar (when employed with the AN/ASN-25 Navigation Computer and a BANDS roller map) as an F-100D/F aircraft navigation system for use during low-level tactical missions.

4. SCOPE OF THE TEST: The following areas were investigated to satisfy the objectives of the test:

a. Determine the suitability of the RYANAV IV Doppler Radar, AN/ASN-25 Navigation Computer, and BANDS Pictorial Display to provide F-100 aircraft with a self-contained navigation system capable of high- or low-level navigation to a target.

b. Determine the accuracy of the combined navigation system and its sensitivity to various types of terrain.

c. Determine if doppler "holes" or "nulls" exist.

d. Determine the attitude and altitude limits of the doppler radar.

5. CONCLUSIONS AND RECOMMENDATIONS: The following conclusions and recommendations are based on information obtained during the flight test.

a. Conclusions:

(1) Installation of this system in the F-100 would greatly improve the aircraft's operational capability, particularly on low-level missions in marginal weather or at night.

(2) The RYANAV IV/ASN-25 Navigation System is highly accurate and insensitive to variations in terrain.

(3) The potential of the RYANAV IV/ASN-25 combination is limited by the inaccurate F-100 heading reference (the J-4 Compass System).

(4) Maintaining a desired course calibration curve for each aircraft would permit the desired course input to be properly biased, substantially reducing cross-track error on certain headings.

(5) The altitude and attitude capability of the RYANAV IV Doppler Radar is more than adequate for normal tactical fighter navigational maneuvering.

(6) An increase in operational flexibility can be obtained by using the midpoint of the takeoff runway as the initial point for the first navigation leg.

(7) A requirement exists for test equipment containing, in addition to malfunction isolation capability, the function of end-to-end calibration of the combined systems.

b. Recommendations:

(1) A navigation system should be installed on all tactical aircraft whose expected life span would warrant the cost of installation. The system selected should have the capabilities and performance characteristics of the system tested or better capabilities if they can be achieved.

(2) The J-4 Compass should be replaced by a more accurate heading reference if a doppler navigation system is installed in the F-100 aircraft.

(3) Test equipment containing the functions of malfunction isolation and end-to-end calibration of the combined system should be included in any production contract.

(4) When employing a doppler navigation system having the capability of zero-altitude operation, the first navigation leg should be computed using the midpoint of the takeoff runway as the initial point.

(5) A desired course calibration curve should be maintained for each aircraft with which the desired course input could be biased to reduce cross-track error.

6. TEST RESULTS AND DISCUSSION:

a. Test Procedures and Environment: As sophisticated ground instrumentation with which doppler accuracy could be measured directly

was not available, the accuracy of the system was determined by measuring its error in position at the end of various navigation legs. In order to minimize errors in the data due to sources other than the navigation system, the initial and terminal points of each of these legs was a VOR station in most cases. This was done for two reasons. First, the geographical coordinates of each VOR station are known precisely and the bearing and distance between them can be computed accurately. Secondly, VOR stations are easily recognized from the air and the aircraft can be accurately positioned over them (within a few hundred feet). VORS were not used in the few instances when the navigation leg was initiated on takeoff roll as would be done operationally.

(1) Each leg used during this test was computed to the nearest tenth of a nautical mile and to the nearest tenth of a degree. However, it is felt that the error in the estimation of average variation and the presence of magnetic anomalies, especially in the area surrounding Nellis Air Force Base, degrade the accuracy of the heading computation to some unknown value. Test data was recorded to the nearest tenth of a mile.

(2) A total of 104 navigation legs with lengths ranging from 59.6 to 618.6 nautical miles were flown during this test. Flights over all types of terrain and one flight over water were included in the test. However, most of the data was obtained from flights over the rocky, mountainous terrain found near Nellis Air Force Base. The data includes flights at high and low altitudes including climbs and descents, and at cruise ground speeds varying from 350 to 550 knots (0.65 to 0.90 Mach).

b. Test Results and Analysis: The combination navigation system was evaluated by determining its performance in three specific areas: position accuracy, altitude capability and attitude limits.

(1) Accuracy:

(a) All accuracies discussed below are stated in percent of distance traveled. That is, a 2.0% error would be a 2.0 nautical mile error at the end of a 100 mile leg, a 4.0 nautical mile error after 200 miles, etc. The along track error is the component of error in the same direction as or parallel to the desired track. Cross track error is the component of error perpendicular to the desired track.

The column labeled "circular error" is the total error which is the vector sum of the along track and cross track errors. The following convention is established to permit labeling the direction of the error consistently. The along track error was noted long and positive when the system would have directed the aircraft beyond the selected check point; the reverse was short and negative. A right and positive cross track error occurred when the aircraft would have been directed to the right of the selected point; the opposite direction was noted left and negative.

(b) The table below summarizes the accuracy demonstrated by the combined navigation system including all effective legs:

TABLE I	ALONG TRACK	CROSS TRACK	CIRCULAR
AVERAGE OR MEAN ABSOLUTE	0.44%	2.29%	2.42%
STANDARD DEVIATION	0.61%	2.98%	------
50% PROBABLE ERROR	0.33%	1.64%	1.86%
75% PROBABLE ERROR	0.55%	3.03%	3.09%

(c) The formulae used to compute the mean absolute and standard deviation is indicated below:

AVERAGE OR MEAN ABSOLUTE $$|\overline{X}| = \frac{1}{N} \sum_{i=1}^{N} |X_i|$$

STANDARD DEVIATION $$S = \left[(\mathrm{rms})^2 - (\overline{X})^2 \right]^{1/2}$$

WHERE: $$\mathrm{rms} = \left[\frac{1}{N} \sum_{i=1}^{N} (X_i)^2 \right]^{1/2}$$

$$\overline{X} = \frac{1}{N} \sum_{i=1}^{N} X_i$$

(d) The plots of error versus number of events from which the probable errors were graphically determined is contained in Annexes A, B and C. These plots will also quickly yield the error for any other selected degree of probability. Although this method of computing probable error would not satisfy the statistician's definition of the term, it does conform with the generally accepted practice within the Air Force of arranging the impacts in increasing order according to the magnitude of the error and selecting the error of the mid-impact as the 50% CEP of the system. This method is used for various reasons, the most important of which is the fact that the distributions under consideration generally do not satisfy the requirements for a rigid determination of CEP. A lack of normality is particularly evident in the case since the error distribution is a severely elongated ellipse (see Annex D).

(e) It can be seen from Table I and Annex D that by far the largest contributor to circular or total error is the cross track component. The cross track error is larger than the along track by a factor near five. It is impossible to determine in a test of this scope the relative magnitude of each of the inaccuracies which contribute to cross track error. However, it is fairly certain that the aircraft heading reference is the largest contributor since a conservative estimate of J-4 Compass System error under dynamic conditions might be $\pm$ 1 degree which is equal to 1.7%. The following are the errors contributing to cross track error:

1. Calculation of true bearing.
2. Calculation of average variation.
3. Calibration of aircraft heading reference.
4. Acceleration effects on aircraft heading reference.
5. Calibration of track input dial.
6. Integration rate in cross track.
7. Drift angle from doppler.
8. Ground speed from doppler.

(f) A plot of cross track error versus desired track (Annex E) indicates that the cross track error varies somewhat consistently as a function of heading for this particular aircraft/navigation system combination.

If a similar record should be kept of cross track error for each aircraft in the field, it would be possible to construct a calibration card in order that a corrected desired track might be set for each navigation leg flown. This would substantially reduce the cross track error on certain headings. However, after each compass swing a new calibration curve would probably have to be initiated.

(g) The small along track error is evidence that the doppler radar's determination of ground speed and the integration accomplished in the AN/ASN-25 Computer was very consistent and the effect of various types of terrain on system accuracy was negligible.

(h) No specially designed test equipment was available for the doppler radar since it was a prototype set. Component changes were made within the doppler radar and the computer which required recalibration of the equipment. After each malfunction and subsequent component change and after the drop tank housing the doppler was removed from the aircraft, the system was calibrated. This was done by flying several legs and removing whatever bias or repeatable error was present by adjusting the doppler radar. The effect of each of these factors on system accuracy and repeatability is not predictable.

(2) <u>Attitude and Altitude Capability</u>: Physical testing was terminated due to an engine malfunction and subsequent change before exact data was obtained on the pitch and roll limitations versus altitude. However, information obtained during the flight test indicated that the attitude capability of the doppler is more than sufficient at all altitudes to permit normal maneuvering during the navigational phase of an operational mission without memory operation. For example, bank angles of 70 to 80 degrees were used frequently on flights at low altitude and bank angles of 50 degrees at 30,000 feet and 30 degrees at 45,000 feet were possible without memory. Afterburner climbs and steep descents were also made without memory. The doppler was noted to supply continuous ground speed and track information during climbs to 45,000 feet, indicating that doppler "holes" or "nulls" do not exist.

(3) <u>Operational Aspects:</u>

(a) Because the ASN-25 Navigation Computer is the bearing and distance-to-go type computer with outputs of nautical-miles-to-go and nautical-miles-off-course, transfer to another leg can only be accomplished at a pre-planned position from which the bearing and distance to some subsequent check point has been precomputed. Therefore, the system under

test has the capability of high or low navigation to a target and return to home base via any number of intermediate check points or IP's. Diversions to alternate or secondary targets are possible only with proper preflight planning. See TAC Test Report 60-51 for detailed discussion.

(b) Since the RYANAV IV has a relatively low altitude and airspeed capability, it is possible to initiate the navigation leg on takeoff roll, eliminating the requirement for proceeding to some point off the runway before turning the AN/ASN-25 to the "run" position. This capability is particularly advantageous at night and/or in adverse weather. When using the takeoff runway as the navigation leg initial point, computing the bearing and distance from the center of the runway will permit takeoffs in either direction according to the surface wind. Switching the AN/ASN-25 from "standby" to "run" as the aircraft passes the mid-point of the runway will provide maximum system flexibility.

(4) <u>Maintainability and Reliability</u>: The doppler radar was unreliable in that it frequently failed and it was difficult to isolate the malfunctions. However, no true determination of maintainability or reliability of the system was obtained during the test for the following reasons:

(a) The doppler radar system was not production equipment, but an engineering prototype.

(b) The entire doppler radar system was installed in a fuel tank carried externally within a different environment than would be experienced in an aircraft fuselage.

(c) No specially designed test equipment was available for the doppler radar or the navigation computer.

(d) No maintenance technical orders were available.

(e) All maintenance functions were accomplished by Ryan Electronics engineers.

7. <u>DEFICIENCIES:</u>

a. The antenna for the prototype radar is too large for practical installation in the F-100 aircraft.

b. No test equipment was available for the combined system to isolate malfunctions or accomplish the necessary end-to-end calibration.

c. Although a navigation system such as the one tested would greatly improve the operational capability of the F-100 aircraft, the accuracy of the J-4 Compass can be considered a deficiency in that it severely limits the accuracy of the combined system.

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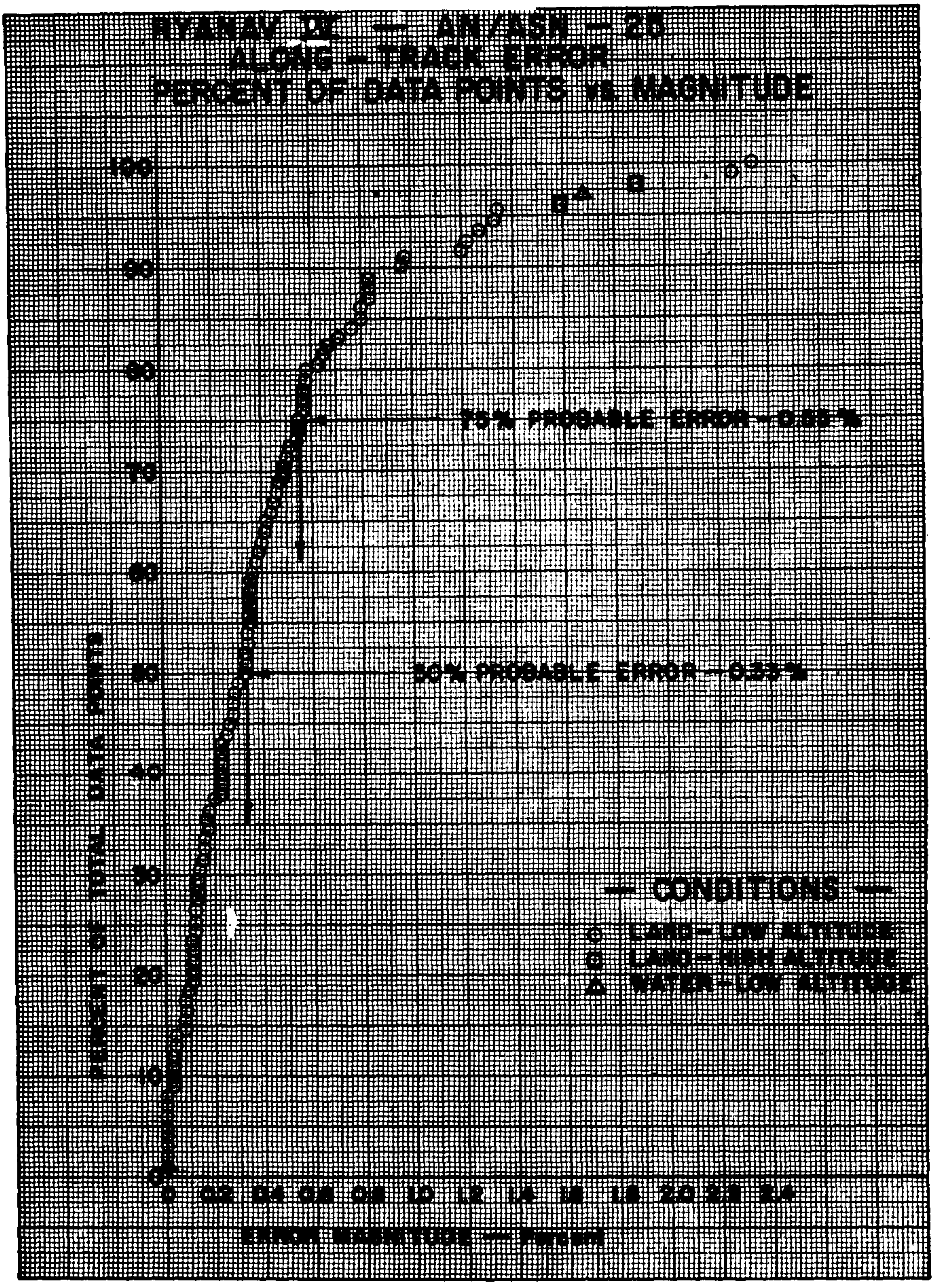
DMEM	1	DORF	1
DMS	1	DOAA	2
DCEE	1	DORQ	10

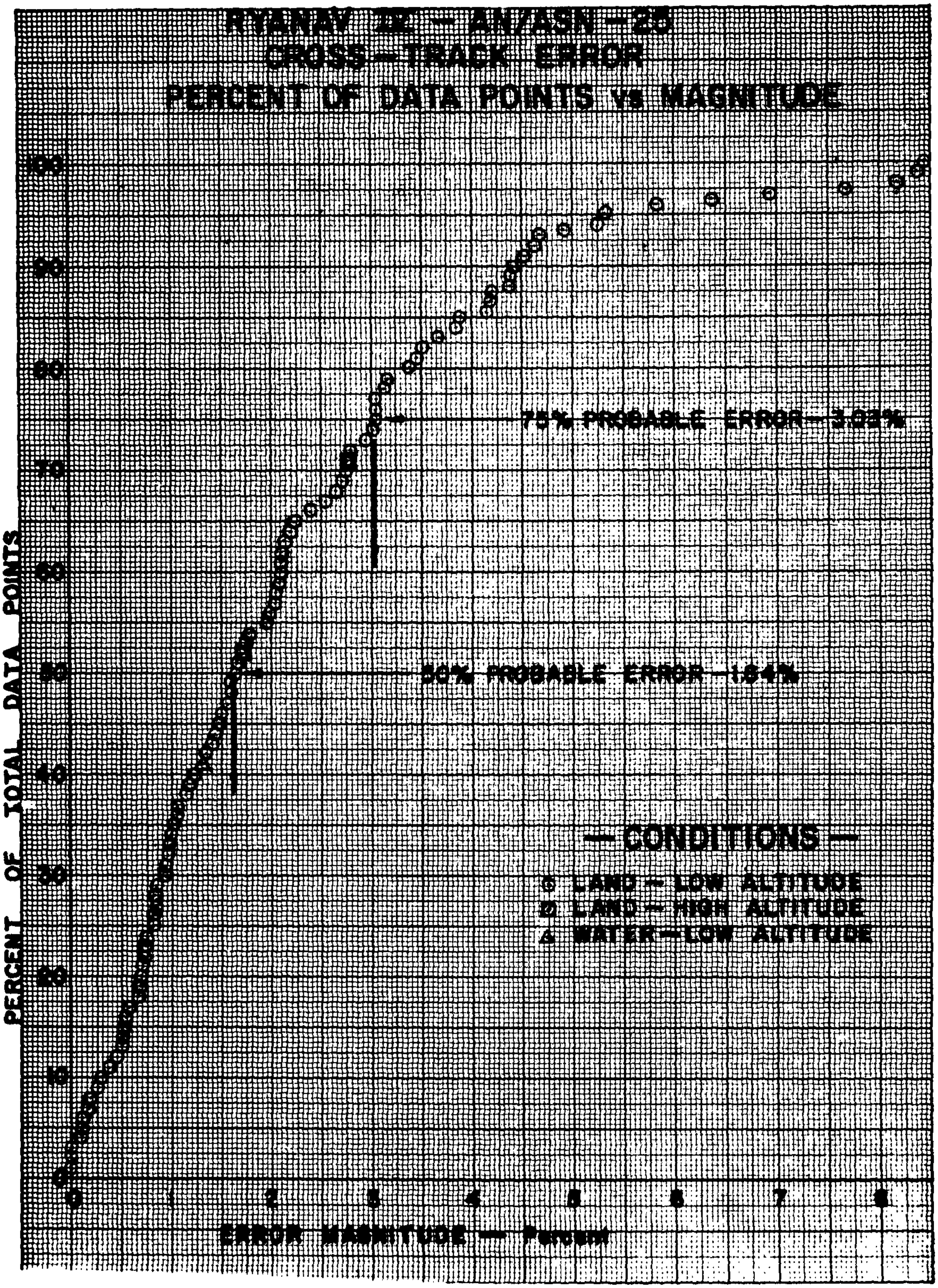
ANNEX A

ALONG-TRACK PROBABLE ERROR


ALONG — TRACK ERROR
PERCENT OF DATA POINTS vs MAGNITUDE
— CONDITIONS —
LAND – LOW ALTITUDE
LAND – HIGH ALTITUDE
WATER – LOW ALTITUDE
PERCENT OF TOTAL DATA POINTS
ERROR MAGNITUDE — Percent

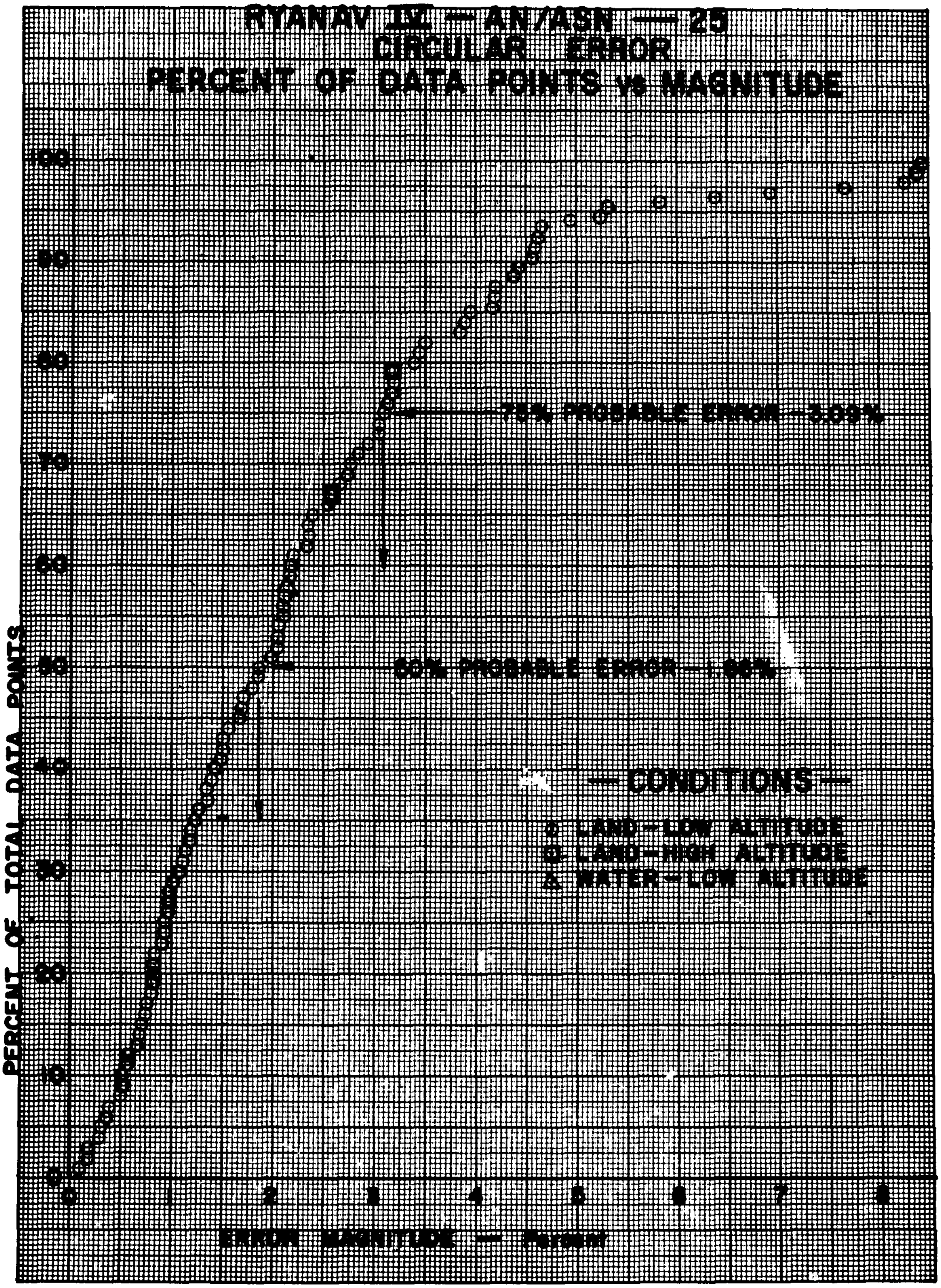
ANNEX B

CROSS-TRACK PROBABLE ERROR


CROSS—TRACK ERROR
PERCENT OF DATA POINTS vs MAGNITUDE
75% PROBABLE ERROR — 3.02%
50% PROBABLE ERROR — 1.64%
— CONDITIONS —
LAND — LOW ALTITUDE
LAND — HIGH ALTITUDE
WATER — LOW ALTITUDE
PERCENT OF TOTAL DATA POINTS
ERROR MAGNITUDE — Percent

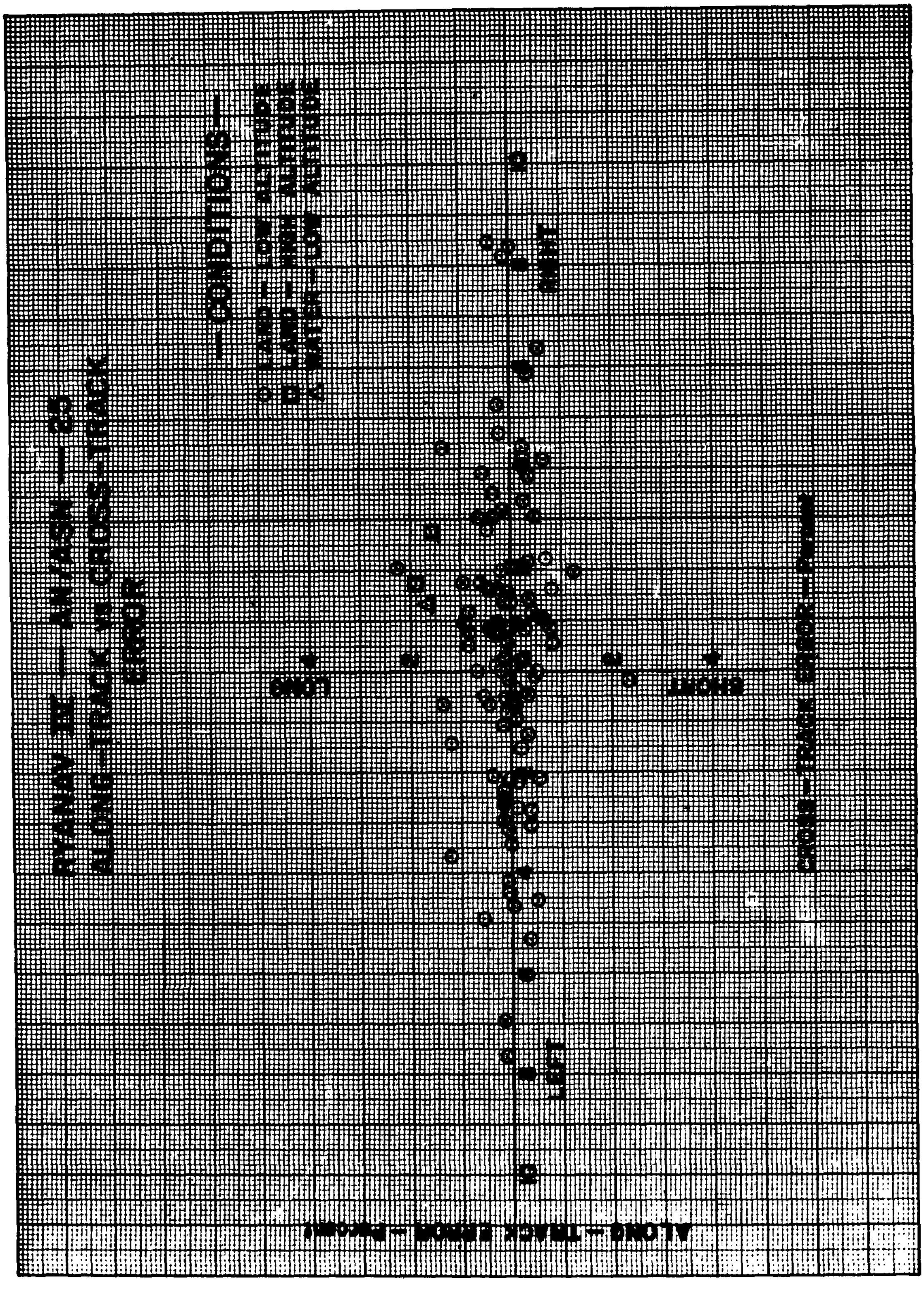
ANNEX C

CIRCULAR PROBABLE ERROR


RYANAV IV — AN/ASN — 25
CIRCULAR ERROR
PERCENT OF DATA POINTS vs MAGNITUDE
75% PROBABLE ERROR
50% PROBABLE ERROR
— CONDITIONS —
LAND — LOW ALTITUDE
LAND — HIGH ALTITUDE
WATER — LOW ALTITUDE
PERCENT OF TOTAL DATA POINTS
ERROR MAGNITUDE — Percent
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8

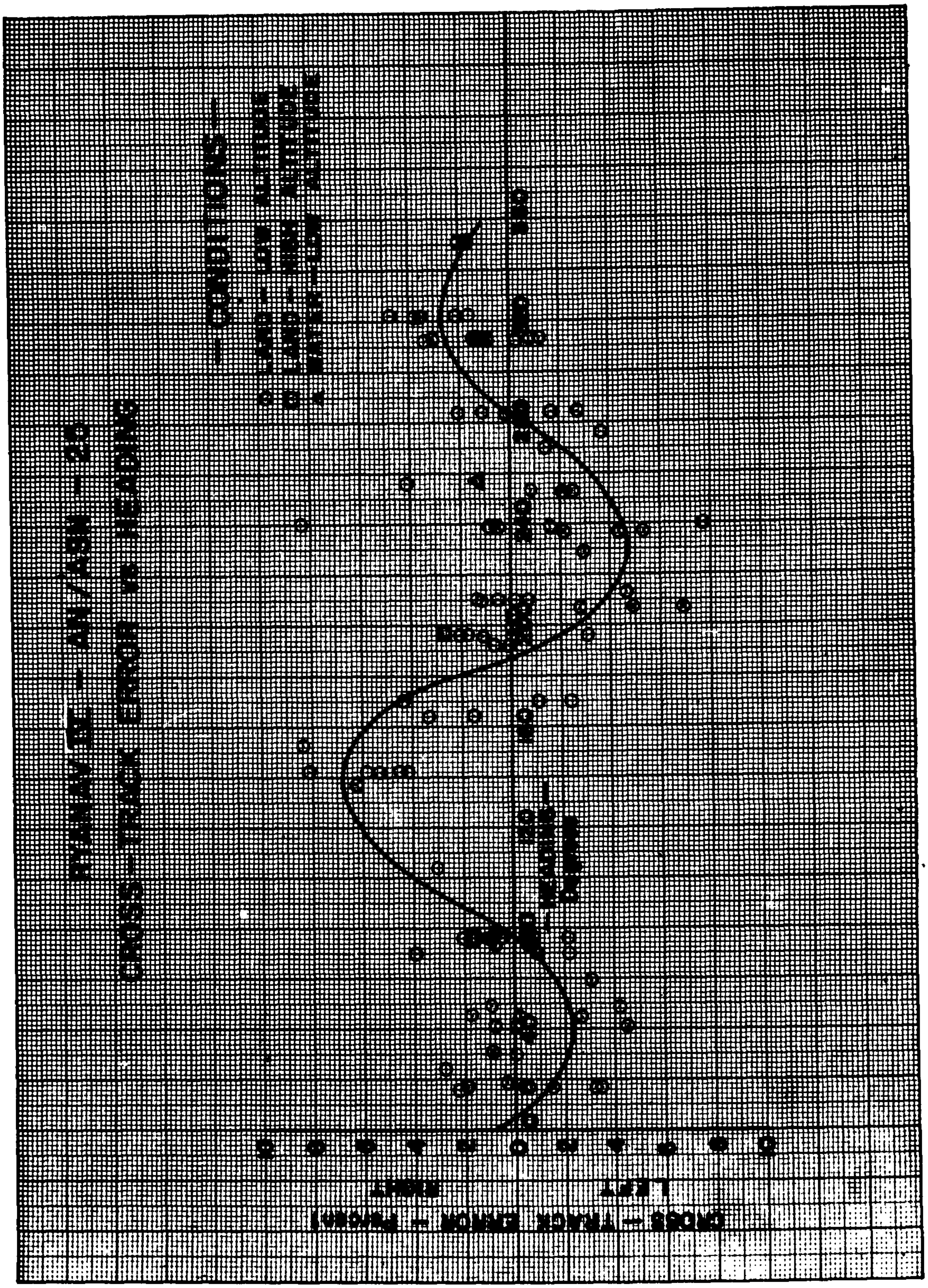
ANNEX D

ALONG-TRACK VERSUS CROSS-TRACK ERROR


RYANAV III — AN/ASN — 25
ALONG-TRACK vs CROSS-TRACK ERROR
— CONDITIONS —
○ LAND — LOW ALTITUDE
□ LAND — HIGH ALTITUDE
× WATER — LOW ALTITUDE
RIGHT
LEFT
LONG
SHORT
CROSS-TRACK ERROR
ALONG-TRACK ERROR

ANNEX E

CROSS-TRACK ERROR VERSUS HEADING


CROSS-TRACK ERROR vs HEADING
CONDITIONS
LEFT
RIGHT

ANNEX F

TEST DATA

ANNEX F

ACCURACY DATA

	Route	Magnetic Bearing	Distance	Along-Track Error	Cross-Track Error
1	Las Vegas - Morman Mesa	030.0	59.6	0.3 Sh	0.0 -
2	Morman Mesa - Las Vegas	210.0	59.6	0.5 Lo	0.7 Rt
3	Morman Mesa - Las Vegas	210.0	59.6	0.5 Lo	0.3 Rt
4	Morman Mesa - Las Vegas	210.0	59.6	0.1 Lo	0.8 Rt
5	Morman Mesa - Las Vegas	210.0	59.6	1.4 Lo	0.1 Lt
6	Morman Mesa - Las Vegas	210.0	59.6	0.8 Lo	0.4 Lt
7	Morman Mesa - Milford	016.4	112.8	0.8 Sh	2.5 Rt
8	Milford - Morman Mesa	196.4	112.8	0.5 Sh	1.3 Rt
9	Milford - Morman Mesa	196.4	112.8	0.5 Sh	2.4 Rt
10	Milford - Morman Mesa	196.4	112.8	0.0 -	2.3 Rt
11	Milford - Morman Mesa	196.4	112.8	1.1 Lo	2.0 Rt
12	Milford - Morman Mesa	196.4	112.8	0.4 Lo	3.4 Lt
13	Milford - Morman Mesa	196.4	112.8	0.2 Lo	0.0 -
14	Milford - Mina	256.4	236.9	1.5 Sh	9.8 Rt
15	Mina - Milford	076.4	236.9	1.3 Sh	2.5 Rt
16	Mina - Milford	076.4	236.9	0.1 Lo	1.2 Rt
17	Mina - Milford	076.4	236.9	1.3 Sh	5.0 Lt
18	Mina - Milford	076.4	236.9	0.4 Sh	2.2 Rt
19	Mina - Milford	076.4	236.9	1.1 Lo	3.8 Rt
20	Mina - Milford	076.4	236.9	0.1 Lo	1.7 Lt
21	Mina - Milford	076.4	236.9	4.5 Lo	4.1 Rt
22	Mina - Beatty	133.5	122.4	0.7 Sh	7.8 Rt
23	Beatty - Mina	313.5	122.4	0.4 Sh	1.8 Rt
24	Beatty - Mina	313.5	122.4	0.0 -	1.0 Rt
25	Beatty - Mina	313.5	122.4	0.4 Sh	1.5 Lt
26	Beatty - Mina	313.5	122.4	0.3 Lo	1.2 Rt
27	Beatty - Mina	313.5	122.4	0.8 Lo	3.8 Rt
28	Beatty - Mina	313.5	122.4	0.5 Lo	1.0 Rt
29	Beatty - Mina	313.5	122.4	0.0 -	1.7 Rt
30	Beatty - Las Vegas	103.6	88.4	0.4 Sh	2.7 Rt
31	Las Vegas - Beatty	283.6	88.4	0.5 Sh	0.9 Rt
32	Las Vegas - Beatty	283.6	88.4	0.3 Sh	0.4 Lt
33	Las Vegas - Beatty	283.6	88.4	0.1 Sh	2.4 Lt
34	Las Vegas - Beatty	283.6	88.4	0.1 Sh	0.6 Lt

	Route	Magnetic Bearing	Distance	Along-Track Error	Cross-Track Error
35	Las Vegas - Beatty	283.6	88.4	0.2 Lo	1.8 Rt
36	Las Vegar - Beatty	283.6	88.4	0.2 Lo	0.1 Rt
37	Parker - Winslow	058.8	201.3	0.8 Sh	6.1 Lt
38	Winslow - Peach Springs	269.4	141.0	1.7 Lo	2.0 Lt
39	Peach Springs - Needles	206.8	69.2	0.4 Lo	3.4 Lt
40	Needles - Las Vegas	321.7	85.7	0.4 Lo	1.4 Rt
41	Needles - Las Vegas	321.7	85.7	0.2 Lo	4.0 Rt
42	Needles - Las Vegas	321.7	85.7	0.3 Sh	3.3 Rt
43	Needles - Las Vegas	321.7	85.7	0.3 Lo	3.0 Rt
44	Needles - Las Vegas	321.7	85.7	0.1 Sh	1.8 Rt
45	Las Vegas - Needles	141.7	85.7	0.1 Lo	7.0 Rt
46	Las Vegas - Needles	141.7	85.7	0.2 Sh	3.6 Rt
47	Las Vegas - Needles	141.7	85.7	0.2 Sh	3.8 Rt
48	Las Vegas - Needles	141.7	85.7	0.3 Sh	5.0 Rt
49	Las Vegas - Needles	141.7	85.7	0.2 Lo	4.5 Rt
50	Needles - Winslow	069.7	182.3	0.2 Sh	4.2 Lt
51	Needles - Winslow	069.7	182.3	0.2 Sh	1.7 Lt
52	Winslow - Prescott	240.2	86.0	0.0 -	7.2 Rt
53	Winslow - Prescott	240.2	86.0	0.1 Lo	6.6 Lt
54	Prescott - Peach Springs	301.6	76.5	0.1 Lo	0.2 Rt
55	Prescott - Peach Springs	301.6	76.5	0.2 Sh	2.6 Rt
56	Peach Springs - Needles	206.8	69.2	0.1 Lo	4.8 Lt
57	Peach Springs - Needles	206.8	69.2	0.2 Sh	1.9 Lt
58	Needles - Zuni	072.8	263.6	1.1 Lo	1.8 Lt
59	Needles - Zuni	072.8	263.6	0.9 Lo	2.0 Rt
60	Needles - Zuni	072.8	263.6	0.3 Lo	1.5 Lt
61	Zuni - Needles	252.8	263.6	0.4 Lo	6.7 Lt
62	Zuni - Needles	252.8	263.6	1.0 Lo	5.5 Lt
63	Zuni - Needles	252.8	263.6	0.2 Lo	2.2 Lt
64	Las Vegas - Hector	204.3	100.3	0.5 Sh	0.1 Lt
65	Hector - Las Vegas	024.3	100.3	0.5 Lo	2.8 Rt
66	Nellis* - Delta	017.2	219.8	0.6 Lo	6.9 Lt
67	Nellis* - Delta	017.2	219.8	2.8 Sh	4.3 Rt
68	Nellis* - Delta	017.2	219.8	0.2 Sh	0.8 Lt
69	Nellis* - Delta	017.2	219.8	1.2 Lo	1.1 Lt
70	Nellis* - Delta	017.2	219.8	0.0 -	7.6 Lt
71	Nellis* - Delta	017.2	219.8	0.2 Sh	3.3 Lt
72	Delta - Currant	238.7	149.7	1.2 Sh	2.4 Lt
73	Delta - Currant	238.7	149.7	0.4 Sh	1.2 Rt

	Route	Magnetic Bearing	Distance	Along-Track Error	Cross-Track Error
74	Delta - Currant	238, 7	149. 7	1, 2 Sh	0, 8 Rt
75	Currant - Nellis*	153, 1	148. 2	0, 6 Lo	12, 5 Rt
76	Nellis* - Grand Junction	045, 1	342, 6	2, 0 Lo	6. 0 Rt
77	Nellis* - Grand Junction	045. 1	342. 6	0, 1 Lo	0. 6 Lt
78	Nellis* - Grand Junction	045, 1	342. 6	0, 8 Lo	9. 1 Lt
79	Grand Junction - Dove Creek	170, 5	75, 1	1. 0 Lo	3. 3 Rt
80	Grand Junction - Dove Creek	170, 5	75. 1	0. 1 Lo	1. 8 Lt
81	Grand Junction - Dove Creek	170, 5	75. 1	0. 1 Lo	0, 8 Lt
82	Dove Creek - Nellis*	236. 9	308. 2	0, 0 -	6, 5 Lt
83	Dove Creek - Nellis*	236, 9	308, 2	1. 1 Sh	16. 4 Lt
84	Dove Creek - Nellis*	236. 9	308, 2	0, 1 Lo	13. 5 Lt
85	Nellis* - Beatty	275. 9	89, 6	1. 1 Lo	3, 3 Lt
86	Morman Mesa - Nellis*	213. 1	47. 5	0, 0 -	2, 2 Lt
87	Delta - Myton	049, 1	122. 4	0. 1 Lo	1, 2 Rt
88	Delta - Myton	049, 1	122, 4	0, 1 Lo	5, 1 Lt
89	Nellis* - Burley	351, 4	384. 5	0. 9 Lo	6, 4 Rt
90	Nellis* - Burley	351. 4	384, 5	0, 3 Lo	7, 6 Rt
91	Burley - Wells	192. 4	99. 5	0, 3 Lo	0, 7 Rt
92	Burley - Wells	192. 4	99. 5	0, 0 -	0, 1 Rt
93	Wells - Nellis*	164. 0	294, 6	0. 5 Lo	9, 3 Rt
94	Wells - Nellis*	164. 0	294, 6	0. 1 Lo	4, 6 Rt
95	Myton - Bryce Canyon	199. 1	180. 4	1, 2 Lo	0, 0 -
96	Myton - Bryce Canyon	199. 1	180. 4	0. 5 Sh	0, 5 Rt
97	Nellis* - Bryce Canyon	041. 2	157. 0	0, 8 Sh	7, 1 Lt
98	Nellis* - Bryce Canyon	041. 2	157. 0	1. 2 Sh	1, 3 Rt
99	Myton - Delta	229. 1	122. 4	0. 2 Lo	3, 6 Lt
100	Delta - Nellis*	197. 1	219. 8	3, 5 Lo	6, 1 Rt
101	MacDill* - Sabine Pass	275. 7	618. 6	10, 4 Lo	8, 1 Rt
102	Sabine Pass - England*	030. 7	125. 3	1. 2 Lo	1, 2 Rt
103	England* - Vienna	079. 1	467. 3	1, 4 Lo	9, 6 Rt
104	Vienna - Myrtle Beach*	070. 0	245. 8	3, 9 Lo	3, 4 Rt

* Denotes mid-point of runway as check point. All others are VOR stations.

Sh Denotes Short
Lo Denotes Long
Rt Denotes Right
Lt Denotes Left

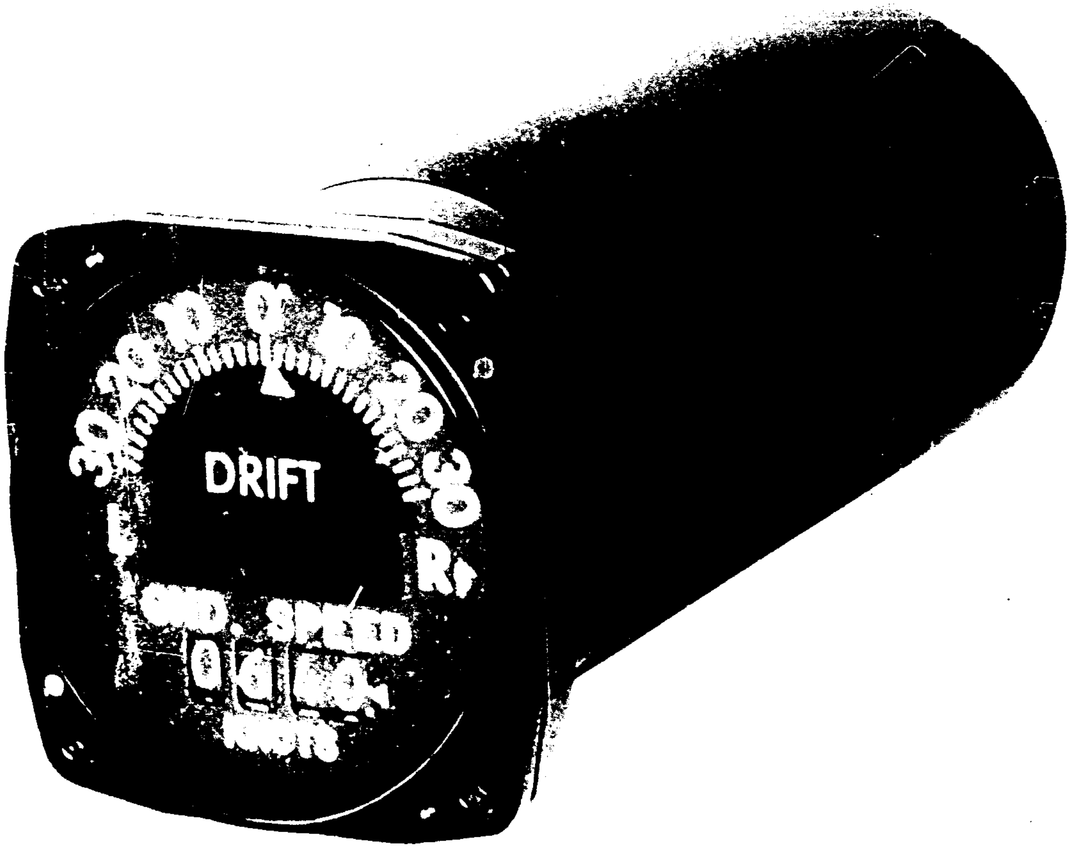
NOTE: BEARINGS ARE IN DEGREES. DISTANCES AND ERRORS ARE IN NAUTICAL MILES.

ANNEX G

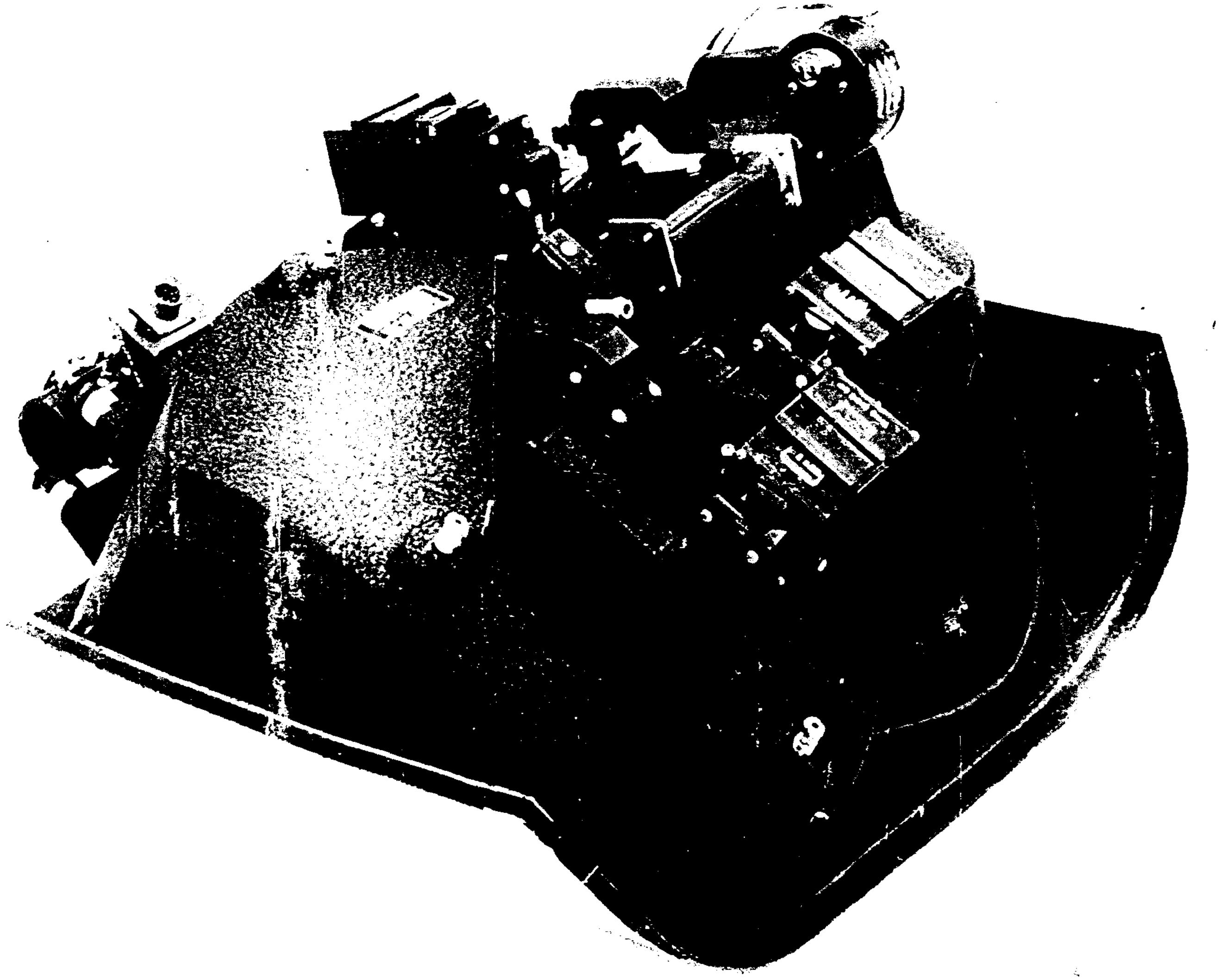
PHOTOGRAPHS

200-Gallon Tank with RYANAV IV Installed

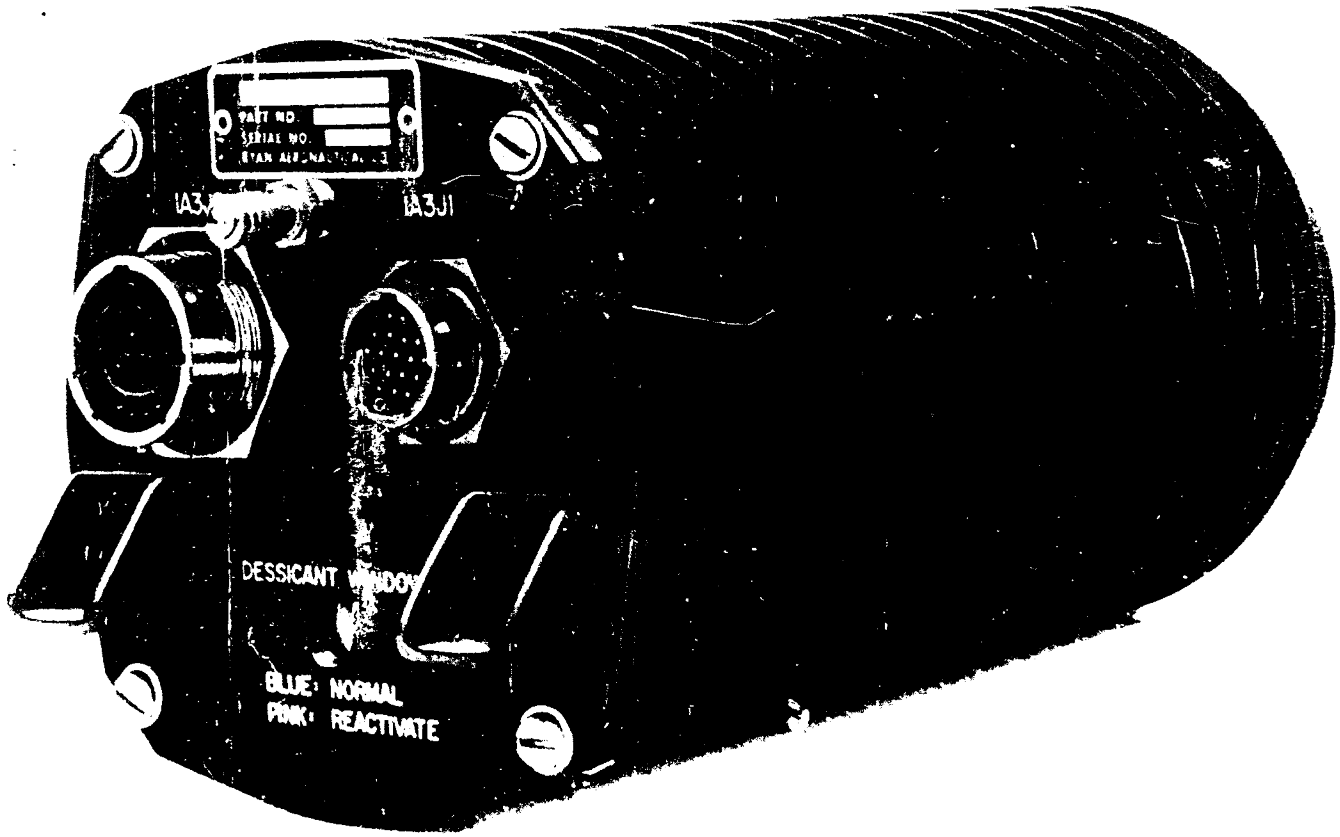
Doppler Radar Control Box



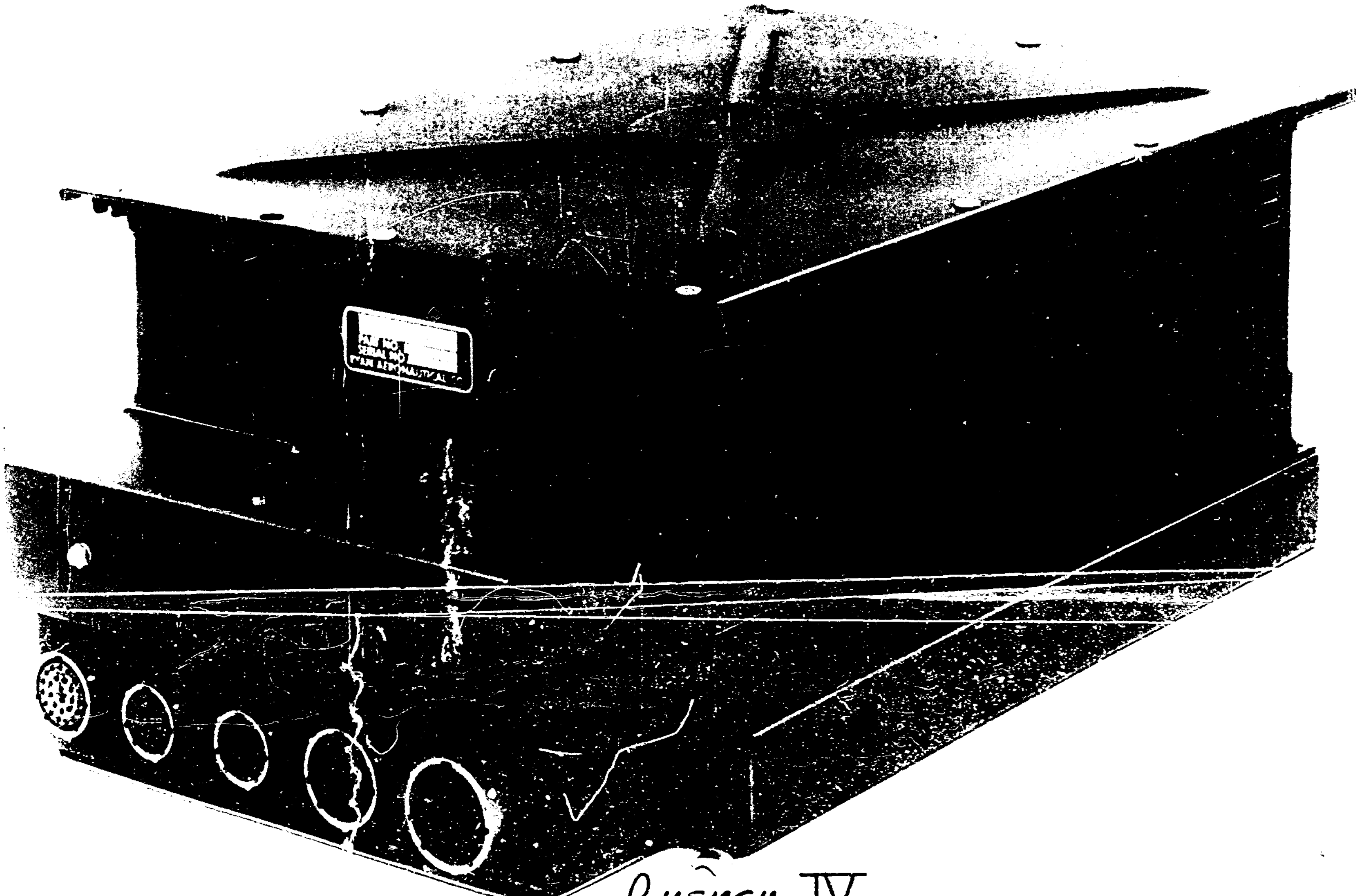
Ground Speed
Drift Angle Indicator



Ryanav IV
Receiver / Transmitter Antenna



Ryanav IV
High Voltage Power Supply



Ryanav IV
Converter / Computer